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SUDDEN DECELERATION OF A FREE JET AT THE ENTRANCE OF A CHANNEL

by

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A family of two-dimensional potential flows is derived which may describe the interaction of a propulsion jet with the leading edge of a thin wing-in-ground effect at zero angle of attack with a deflected trailing edge flap. Assuming that such flows occur at the leading edge, the static performances of this arrangement—called the Power Augmented Ram Wing—are derived as functions of geometry. A minimum power point

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NOTATION

C_p	Pressure coefficient
C_T	T_{net}/T_j
F	Complex potential
f	Strength of sink representing flow down channel
h	Height of wing bottom surface above water
P_c	Static pressure under wing (gage)
q_j	Dynamic pressure of propulsion jet
r	Velocity of flow in channel divided by jet velocity
T_j	Thrust of propulsion jet
T_{net}	Net thrust on vehicle
t_1	Propulsion jet thickness
t_2	Thickness of jet leaving under trailing edge of flaps
u	Hodograph plane real component
v	Hodograph plane imaginary component
w	Complex velocity $= u + iv$
x	Real coordinate in physical plane
y	Imaginary coordinate in physical plane
z	Complex coordinate in physical plane $= x + iy$
β	Angle between spillage jet velocity and incoming jet velocity

ABSTRACT

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which may describe the interaction of a propulsion jet with
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ADMINISTRATIVE INFORMATION

INTRODUCTION

The potential flow problem is described in Figure 1. The jet,
entering from the left, interacts with the channel entrance with part
of the flow leaving in the channel at reduced velocity and part spill-
ing around the lip and leaving at some angle β. The flow is symmetrical
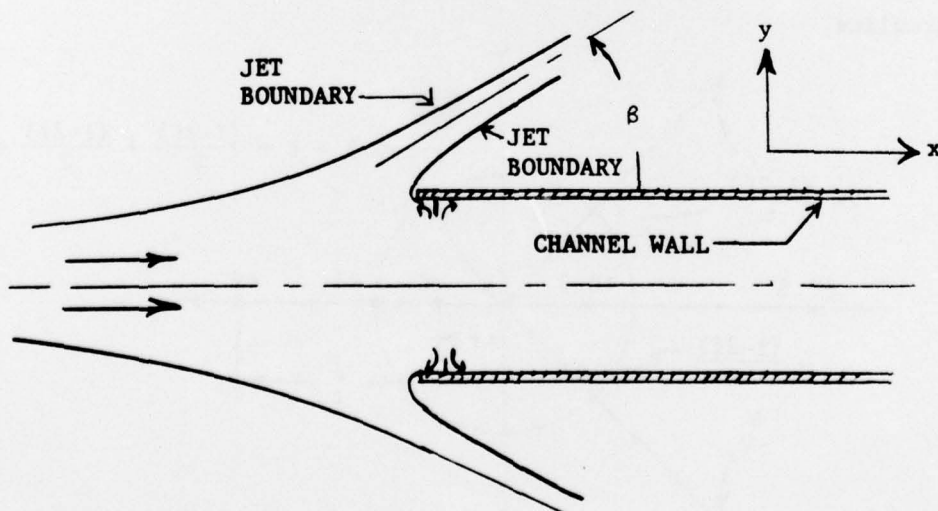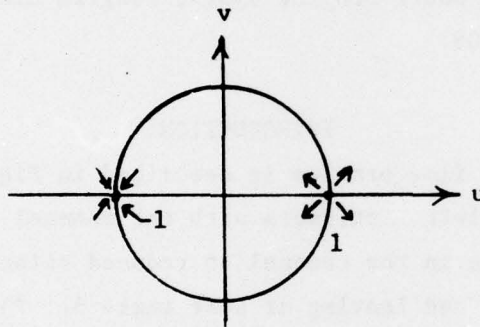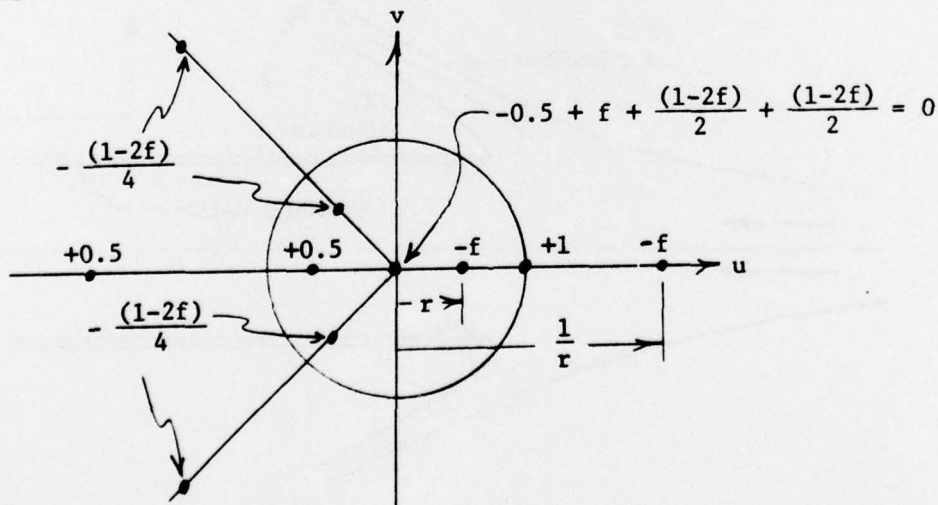

Figure 1 - Physical Plane (z)

about a horizontal line and so it is appropriate to consider only
one half. It is thought the horizontal center line could represent
the water surface and the duct wall could represent the leading
edge of the wing in application to the Power Augmented Ram Wing.

THE CONJUGATE HODOGRAPH

To construct the conjugate hodograph flow, one can start with
a source of unit strength at $w = +1$ and a sink of unit strength at
$w = -1$. The flow is known to have a unit circle streamline which
will have to be preserved to develop the free jet boundaries.

Add the following source sink systems which preserve the circular
streamline.

$$-0.5 + f + \frac{(1-2f)}{2} + \frac{(1-2f)}{2} = 0$$

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All source sink pairs, except those along the real axis, are
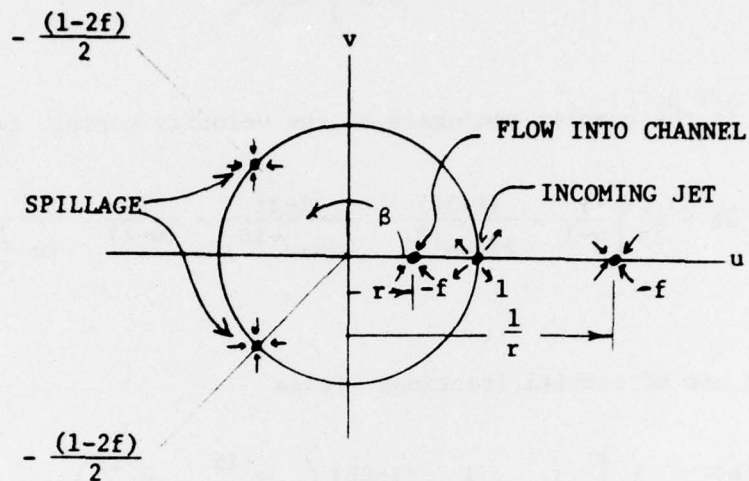allowed to close on the unit circle yielding the conjugate
hodograph of interest.

Figure 2 - The Conjugate Hodograph (w)

The complex potential in the w-plane can be easily written

$$F(w) = \frac{1}{2\pi} \left[\ln(w-1) - \frac{(1-2f)}{2} \ln(w-e^{i\beta}) - \frac{(1-2f)}{2} \ln(w-e^{-i\beta}) \right.$$

$$\left. - f\ln(w-r) - f\ln\left(w-\frac{1}{r}\right) \right] \tag{1}$$

3

THE TRANSFORMATION

To derive the transformation to the physical plane, the relation

$$z = \int \frac{dF(w)}{w},$$

where w is the complex conjugate of the velocity vector, is used.

$$dF = \frac{1}{2\pi} \left[\frac{1}{w-1} - \frac{(1-2f)}{2(w-e^{i\beta})} - \frac{1-2f}{2(w-e^{-i\beta})} - \frac{f}{(w-r)} - \frac{f}{(w-\frac{1}{r})} \right] dw$$

Repeated use of partial fractions yields

$$\frac{dF(w)}{w} = \frac{1}{2\pi} \left[\frac{1}{(w-1)} - \frac{1}{w} - \frac{(1-2f)}{2} \left(\frac{e^{-i\beta}}{(w-e^{i\beta})} - \frac{e^{-i\beta}}{w} \right) \right.$$

$$- \frac{1-2f}{2} \left(\frac{e^{i\beta}}{(w-e^{-i\beta})} - \frac{e^{i\beta}}{w} \right) - f \left(\frac{\frac{1}{r}}{(w-r)} - \frac{\frac{1}{r}}{w} \right)$$

$$\left. - f \left(\frac{r}{(w-\frac{1}{r})} - \frac{r}{w} \right) \right] dw .$$

The 1/w terms are now grouped.

$$\frac{dF(w)}{w} = \frac{1}{2\pi} \left[\frac{1}{(w-1)} - \frac{(1-2f)e^{-i\beta}}{2(w-e^{i\beta})} - \frac{(1-2f)e^{i\beta}}{2(w-e^{-i\beta})} - \frac{f}{r} \frac{1}{(w-r)} - \frac{fr}{(w-\frac{1}{r})} \right.$$

$$\left. + \frac{1}{w} \left(-1 + \frac{(1+2f)e^{-i\beta}}{2} + \frac{(1-2f)e^{i\beta}}{2} + \frac{f}{r} + fr \right) \right] dw$$

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The transformation cannot have a singularity at the origin of the hodograph as this point must correspond to a stagnation point. Therefore, the coefficient of 1/w yields a relation between f and r.

$$\frac{f}{r} + fr + \frac{(1-2f)(e^{-i\beta}+e^{i\beta})}{2} - 1 = 0$$

$$f = \frac{r(1 - \cos \beta)}{(r^2 - 2r \cos \beta + 1)} \tag{2}$$

Equation (2) could also have been derived directly from the requirement that the velocity induced at the origin by the source sink distribution in the hodograph plane must be zero. Now the indicated integration is performed, resulting in the required transformation.

$$z = \frac{1}{2\pi}\left[\ln(w-1) - \frac{(1-2f)e^{-i\beta}}{2}\ln(w-e^{i\beta}) - \frac{(1-2f)e^{i\beta}}{2}\ln(w-e^{-i\beta})\right.$$

$$\left. - \frac{f}{r}\ln(w-r) - fr\ln(w-\frac{1}{r})\right] \tag{3}$$

EXAMPLE RESULTS

Two specific cases are presented: one corresponding to the "filled duct" and the other to the "overfilled duct." The principal results from these two examples are given in Figures 3 and 4, respectively. The "filled duct" case, Figure 3, emerges from the solution when $\beta = \pi$. In the "filled duct" case, the duct leading edge goes to $-\infty$ to the left, indicating that this particular solution could occur at any point between parallel walls. This raises some concern that in the Power Augmented Ram Wing the pressure jump need not occur as desired near the leading edge.
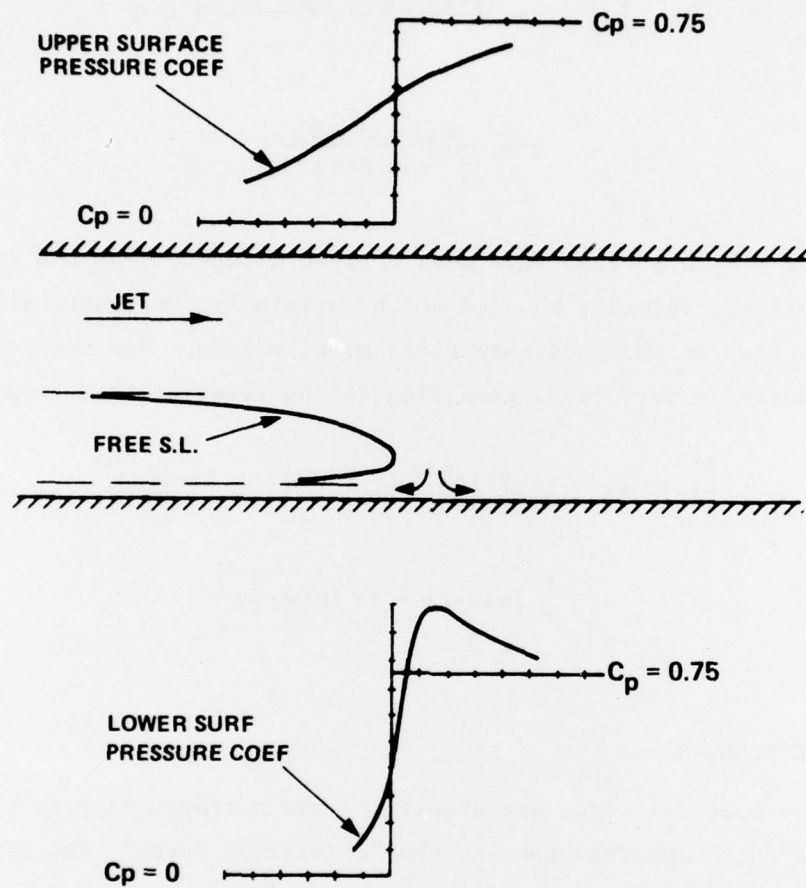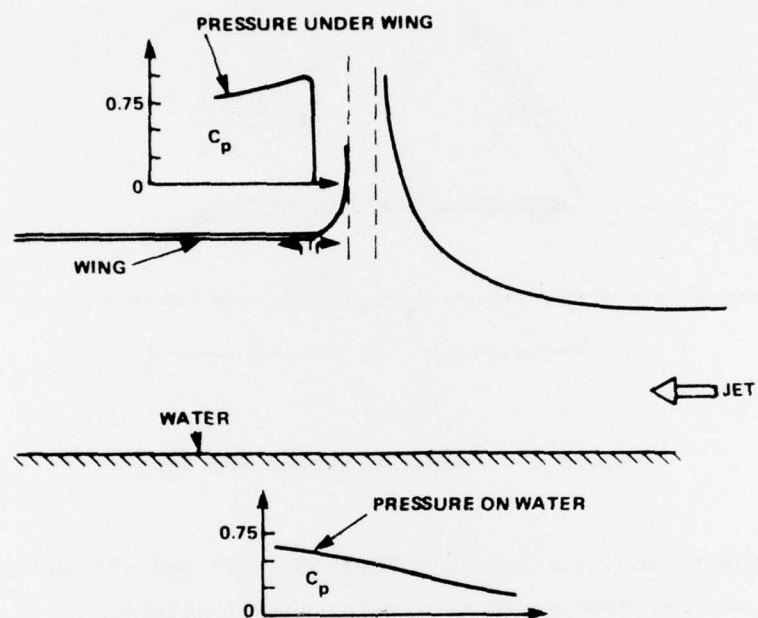
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Figure 3 - Filled Duct, $\beta = 180°$, $r = 0.5$

Figure 4 – Overfilled Duct, β = 90°, r = 0.5

APPLICATION TO THE POWER AUGMENTED RAM WING

Using the potential flow solution developed above, one can develop certain useful relations applicable to the Power Augmented Ram Wing. Figure 5 defines certain geometric parameters.
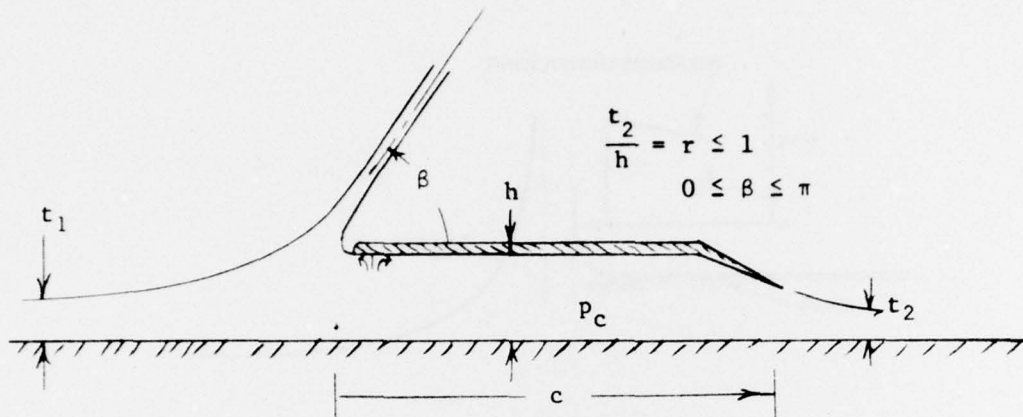

$$\frac{t_2}{h} = r \leq 1$$
$$0 \leq \beta \leq \pi$$

Figure 5 – Power Augmented Ram Wing

By systematic substitution into Equations (2) and (3) and assuming $h \ll c$, one can develop the following useful relations.

$$\frac{t_2}{t_1} = 2f = \frac{2\left(\frac{t_2}{h}\right)(1 - \cos\beta)}{1 - 2\left(\frac{t_2}{h}\right)\cos\beta + \left(\frac{t_2}{h}\right)^2} \tag{4}$$

$$\frac{h}{t_1} = \frac{t_2/t_1}{t_2/h} \tag{5}$$

$$C_p = 1 - \left(\frac{t_2}{h}\right)^2 \quad \text{(pressure coefficient)} \tag{6}$$

$$C_T = (1 - \cos\beta)\frac{t_2}{t_1} + \cos\beta \quad \text{(thrust coefficient)} \tag{7}$$

8

One can suppose that a specific pressure under the wing and a specific thrust are required and that it is desirable to minimize the power in the incoming jet.

$$T_{net} = T_j \ C_T$$

$$p_c = C_p \ q_j$$

$$\text{Power} \propto T_j \ \sqrt{q_j} = \frac{\sqrt{p_c} T_{net}}{C_T \sqrt{C_p}} \tag{8}$$

Therefore, it is desirable to maximize $C_T \sqrt{C_p}$.

Figure 6 was generated using Equations (4), (5), (6), (7), and (8). The interesting conclusion from Figure 6 is that the most useful solutions occur for rather high thrust coefficients. The overfilled duct out-performs the filled duct with respect to $C_T \sqrt{C_p}$. However, this performance is achieved at a reduced value of h/t compared to the filled duct case.
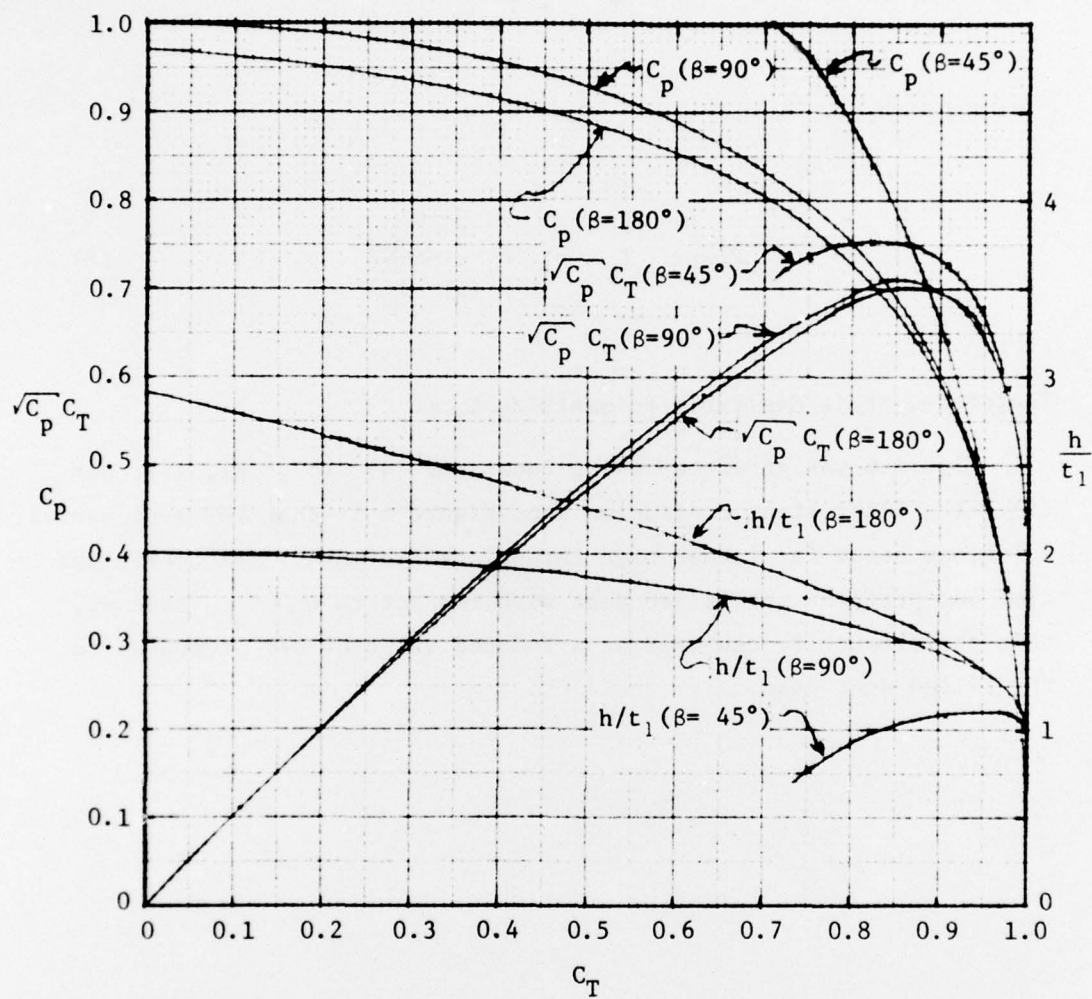
Figure 6 – Power Augmented Ram Wing Performance Parameters

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